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## Chapter Eight

# Timber Structures Design

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### 8.1 INTRODUCTION

As of 2005, almost three percent of Delaware's bridges were timber.

DelDOT's construction of timber bridges has decreased in proportion to its use of other materials over the last 50 years. This is due to an increasing use of steel and concrete to accommodate longer spans, increased traffic and larger truck loads. Today, most new timber bridges constructed by DelDOT are single spans over tax ditches and creeks on low-volume roads.

Other uses of timber by DelDOT include piles, barriers, railings, boardwalks, decks, fender systems, privacy fences, landscaping, railroad ties, and retaining walls.

This chapter will discuss general aspects of timber bridges, physical and mechanical properties of timber, preservatives, hardware, design criteria, and the design of various components of bridges using wood. These topics will be discussed in enough detail to give designers the insight needed to design timber bridges that are constructable, functional, durable, and maintainable. Emphasis will be placed on the types of timber bridges in use on the state's highway system. Where appropriate, the designer is referred to other references for details not presented here.

#### 8.1.1 ADVANTAGES AND DISADVANTAGES OF TIMBER BRIDGES

The main advantages of timber bridges relative to other bridge materials are:

- Ease of construction;
- Ease of maintenance;
- Pleasing appearance;
- Renewable resource;
- Construction is not weather-dependent;
- Lightweight.

The main disadvantages of timber bridges are:

- Susceptibility to vandalism.
- Rapid decay in the absence of proper treatment.
- The need to account for irregularities in the material in design and construction.
- Frequent maintenance requirements.

#### 8.1.2 TIMBER AS A BRIDGE MATERIAL

Timber can be used to construct many different types of bridge systems. In Delaware, some of them are:

- Beam

- Deck
- Truss

Most timber bridges currently being built in the state are laminated deck type systems. However, many beam type systems constructed prior to the 1960's are still in DelDOT's bridge inventory.

Many different qualities and species of wood are available for construction. Because of the large variation in timber qualities, the bridge designer must carefully specify wood materials. This is to insure that the timber specified is available, durable, and can safely carry the design loads and satisfy serviceability limit states.

Construction of timber beam and deck bridge systems in Delaware is carried out using various types of lumber. Variations in lumber used in bridge construction include:

- Species of the tree;
- Physical properties of the lumber;
- Mechanical properties of the lumber;
- Sawn or laminated lumber;
- Preservative treatments.

Additional design considerations are:

- Superstructure type;
- Types of fasteners;
- Railings;
- Wearing surfaces;
- Fire resistance and/or protection;
- Substructure type.

### **8.1.2.1 TIMBER BEAM SUPERSTRUCTURE**

Beam type systems are the simplest type of timber bridge. Most consist of a series of longitudinal beams supported by piers and abutments. Typically spans can range from 10 to 30 ft [3 to 9 m] depending on the

beam type. Most of the bridges of this type on Delaware's highway system were built prior to the 1960's. Timber beam systems include:

- Sawn Lumber Beams
- Glue Laminated Beams

Most timber beam type bridges in Delaware are sawn lumber beams, and most range in span from 10 to 20 ft [3 to 6 m]. The beams are typically less than 3 feet [1 m] apart, and are commonly 4 to 8 in [100 to 200 mm] wide and 12 to 18 in [300 to 450 mm] deep. Decks on beam superstructures are typically constructed of 2 to 4 in [50 to 100 mm] thick planks placed transverse to the beams. The planks are typically not overlaid with a wearing surface, because they deflect under load, causing cracking of the wearing surface.

### **8.1.2.2 LONGITUDINAL DECK SUPERSTRUCTURES**

Longitudinal deck superstructures are the primary types of timber bridges currently being constructed in Delaware. Longitudinal deck superstructures are constructed by glue laminating timber planks together to form panels, and then, if possible, stress laminating the panels together to form a rigid deck unit. The deck is typically overlaid with hot-mix. See Section 8.7 for more design details.

Longitudinal deck superstructures are typically between 8 and 16 in [200 and 400 mm] deep. They can be used economically and practically for clear spans up to approximately 30 ft [9 m]. The low profile of these bridges makes them desirable when vertical clearance below the bridge is limited.

## **8.2 PHYSICAL PROPERTIES OF STRUCTURAL TIMBER**

Physical properties of wood refer to its natural qualities. Numerous factors have an effect on the physical properties of wood. Designers must be aware of these factors and specify allowable mechanical properties for use in design. Mechanical properties of lumber are discussed in Section 8.3. Factors having an effect on the physical properties of wood are:

- Species
- Direction of grain
- Moisture content
- Density
- Knots
- Durability

### **8.2.1 LUMBER SPECIES**

Lumber is manufactured from a great variety of timber species. Physical properties of each species vary. Some species of timber are strong and durable, while others are not. Species with similar mechanical properties are classified into groups. Typically, several species suitable for bridge construction are available in a given location. In Delaware, the preferred species for use in bridge construction are Douglas fir and southern yellow pine. For the replacement of historic covered bridges, the exotic fire-resistant wood bongossi/azobe (*Lophira alata*) may be used with the approval of the Bridge Design Engineer.

### **8.2.2 DIRECTION OF GRAIN**

Wood grows as fibers that run in the direction of the tree trunk. Parallel to the

wood fibers is “with the grain”. Perpendicular to the direction of the fibers is “against the grain”. Wood has different structural properties in each of these directions, which must be accounted for in design.

### **8.2.3 MOISTURE CONTENT**

Moisture content of wood is the weight of water it contains divided by its dry weight. Moisture content is typically expressed as a percentage. Moisture content of timber varies by species and structural application. Wood is a hygroscopic material, which means that it absorbs moisture in humid environments and loses moisture in dry environments. As the moisture content of wood changes, so does its strength. Wood with lower moisture content has higher strength. The factors used to make strength adjustments based on changes in the physical condition of wood are given in Section 8.3.4.2. Moisture content of wood used in timber bridges is a function of use above or below the water line, temperature, and humidity.

As the moisture content of wood changes, wood shrinks and swells. With the grain, average shrinkage values for green to oven dry conditions range between 0.1 and 0.2 percent; this is generally of no concern to the designer. Against the grain, shrinkage is much more pronounced. The effect of uneven drying in two different directions perpendicular to the grain can cause wood to warp. This commonly occurs in thin planks. Typically, bridge designers do not have to make shrinkage calculations; however, they should understand how shrinkage occurs and guard against its detrimental effects.

## 8.2.4 DENSITY

Density of wood varies with species and moisture content. Density for most species varies between 20 and 50 pcf [320 and 800 kg/m<sup>3</sup>]. For most bridge applications, density is taken as 50 pcf [800 kg/m<sup>3</sup>]. The density of bongossi is 66 pcf to 75 pcf [1060 to 1205 kg/m<sup>3</sup>]. Density of wood and strength are closely related. Generally, as density increases, strength increases proportionally. Density is also important in buoyancy calculations.

## 8.2.5 KNOTS

Knots are formed by a branch that has been surrounded by growth of the trunk. Knots reduce the strength of wood because they interrupt the continuity and direction of wood fibers.

## 8.2.6 DURABILITY

The natural durability of wood is defined as its resistance to decay and insect attack. Natural durability of wood varies with species. In general, only the heartwood of a tree is considered naturally durable. Heartwood is the interior of the tree trunk which is composed of inactive wood cells. Because of variations in durability, it is unreliable for the bridge designer to depend on natural wood durability in structural applications. Therefore, the wood used in structural applications is treated to resist decay and attack from insects. Preservative treatments for wood will be further discussed in Section 8.4.

# 8.3 MECHANICAL PROPERTIES

Mechanical properties describe the characteristics of a material in response to externally applied forces. Designers are

mainly concerned with elastic and strength properties.

Elastic properties relate a material's resistance to deformation under an applied load and ability of the material to regain its original dimensions when the load is removed. There are three elastic properties of wood: modulus of elasticity, shear modulus, and Poisson's ratio. Each of these elastic properties has different values depending on species, grade, and orientation of the applied load to the direction of the grain. The only elastic property of wood that is typically required in bridge design is modulus of elasticity in the longitudinal direction. This value relates the stress occurring in that direction to the strain occurring along the same axis.

Strength properties describe the ultimate resistance of a material to applied loads. They include compression, tension, shear, bending, and torsion. As with elastic properties, strength properties of wood vary in different directions along the grain and with species and grade.

Mechanical properties of wood vary greatly. Even timber members cut from the same log can have widely varying mechanical properties. The mechanical properties of any given member are a direct result of its inherent physical properties. This leads to a fairly elaborate system for both lumber grading at the mill and determination of mechanical properties to be used in design. Wood strength and elastic design values are found in the *AASHTO Specifications*, Section 8.4.

## 8.3.1 SAWN LUMBER GRADING

Mechanical properties of sawn lumber are a function of species, physical condition of the member, size, and structural application.

When lumber is cut from a log, the properties of the individual pieces vary considerably in strength and stiffness. To obtain reliable engineering properties, lumber is visually graded at the mill by trained inspectors or by mechanical methods, which actually stress each piece to determine its strength. The grade of visually graded lumber is directly related to the number, character, and location of features that lower the strength, stiffness, or durability of the piece. Common factors which affect lumber grade are knots and slope of the grain.

### 8.3.1.1 Grading Rules

Grading of lumber varies by size classification. Grades for dimensional lumber are standardized by the National Grading Rule (NGR). For larger sizes, grading is not standardized but is controlled by various grading rule agencies. In turn, these grading agencies provide tabulated values for that grade that can be used for structural calculations. Design values for lumber used on DelDOT projects shall be obtained from the *AASHTO Specifications*, Section 8, to the extent possible. The process of establishing design properties for visually graded lumber is contained in *ASTM D245, Standard Methods for Establishing Structural Grades and Related Allowable Properties for Visually Graded Lumber*.

The American Lumber Standards Committee performs quality control of lumber grading practices.

### 8.3.1.2 Specifying Allowable Timber

DelDOT practice is to specify two criteria that must be met for lumber used on bridge projects: minimum mechanical properties

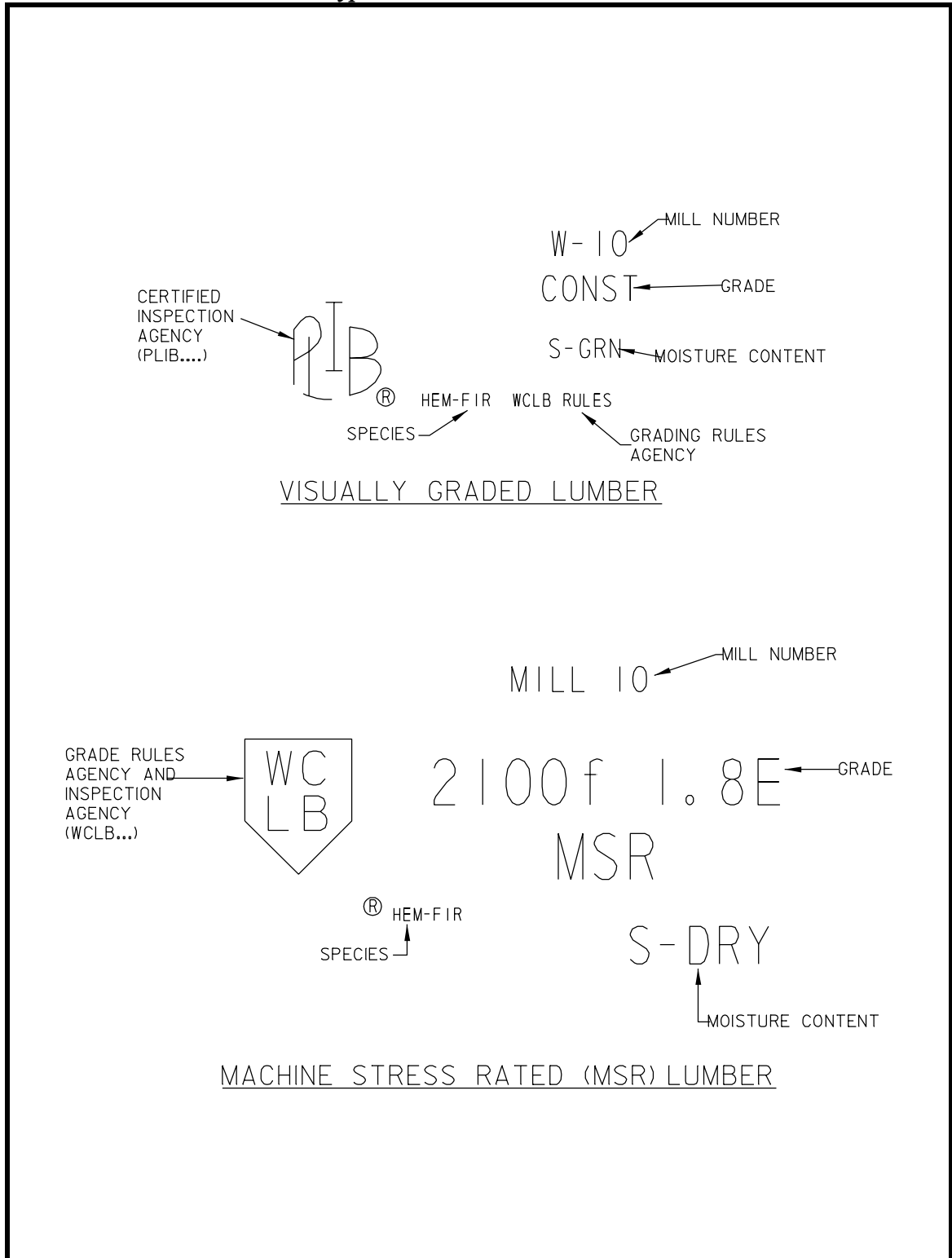
and acceptable species and grade. The designer uses these mechanical properties in design calculations. DelDOT typically uses Grade I southern yellow pine or Douglas fir.

To ensure that the lumber supplied meets specifications, the contractor is required to submit shop drawings of all structural elements for review and acceptance. The shop drawings must indicate the saw mill supplier, species, grade and grading rules used. During construction, the lumber supplied must be marked in accordance with industry standards to identify properties for that species and grade. Typical quality marks for visually and mechanically graded sawn lumber are shown in Figure 8-1, and include the following:

- Grade;
- Species of wood;
- Grading rules agency used for grading;
- Inspection agency;
- Moisture content at the time of surfacing;
- Mill number or name.

Lumber is also inspected for conformity with plans and specifications by DelDOT Materials and Research personnel or their representatives. Each piece of lumber is inspected and, if acceptable, is hit with a DelDOT hammer mark. This inspection normally is performed at the preservative treatment facility after the lumber has been treated. Lumber may be rejected due to failure to meet specification tolerances for warpage, splits, checks, dimensional variations, inferior grade, preservative retention and others. At the job site, construction inspection personnel must verify that all lumber delivered has been inspected and accepted.

**Figure 8-1**  
**Typical Lumber Grade Mark**



### 8.3.2 LUMBER SIZES

Lumber sizes are typically recorded in nominal dimensions, which are not the actual size of the piece. Nominal dimensions of lumber are always greater than the actual net dry dimensions of the piece. The actual net dry dimension of the piece will vary depending on the type of surfacing: dressed, rough-sawn, or fully sawn.

Dressed lumber is used in most bridge design applications. Dressed lumber is run through a plane after sawing to give it a smooth finish. This is referred to as surfaced four sides (S4S). The S4S process reduces the size of the lumber. Unless otherwise specified, all lumber used in DelDOT bridge construction shall be cut square and surfaced on four sides. Net dry dimensions for dressed lumber are given in the *AASHTO Specifications*, Section 8. Designers must use the actual net dry dimension of the piece in all calculations and design. Measurement for payment of timber is based on nominal width, thickness and the actual length of the pieces in the finished structure.

Exceptions where dressed lumber is not used is with timber piles, pile caps, decking, and timber roadway guardrail. All glulam members are specified and constructed actual sizes. Glulam members are manufactured from 1 1/2" [38 mm] lumber laminations (western species) on 1 3/8" [35 mm] laminations (southern pine). Standard finish dimensions for glulam members are given in the *AASHTO Specifications*, Section 8. Timber pile sizes are specified by a minimum butt diameter. The size and surface treatment of timber piles is specified in the DelDOT Standard Specifications. The minimum tip diameter of timber piles varies

between 7 and 8 in [175 to 200 mm] based on the length of the pile.

Lumber is typically produced in 2-ft [610 mm] lengthwise increments. In width and thickness, common sizes vary from 2 to 16 in [50 to 400 mm]. Available sizes should be confirmed prior to specifying them.

### 8.3.3 MECHANICAL PROPERTIES OF GLUE LAMINATED TIMBER (GLULAM)

Bonding planks of wood together creates glue-laminated timber. The planks are bonded together on their wide face. Bonding is carried out using adhesives. This process has the following advantages:

- Beams can be produced in virtually any size and a variety of shapes.
- Increased strength is obtained by dispersing strength-reducing characteristics throughout the member.
- Better dimensional stability is achieved because the beams are manufactured from dry lumber.

#### 8.3.3.1 Product Standards

Standards for glulam lumber are provided by the *American National Standard for Wood Products - Structural Glue Laminated Timber, ANSI/American Institute of Timber Construction (AITC) A190.1*. This standard contains requirements for the production, inspection, testing and certification of structural glulam. Glulam can be manufactured from any lumber species provided it meets necessary grading and stiffness criteria. Laminations are selected from stress-graded sawn lumber. Normal moisture content of the lumber at the time of gluing should not exceed 16%, and the maximum lamination thickness should not

exceed 2 in [50 mm]. Lumber used on DelDOT projects is kiln-dried Douglas fir or southern pine, and engineering properties shall be as noted on the plans.

### **8.3.3.2 Adhesives**

Adhesives used in the glulam process must be capable of developing shear strength in excess of the wood capacity. Adhesives must be “wet-use” adhesives conforming to the Voluntary Product Standard PS-56-73 of the U.S. Department of Commerce, National Bureau of Standards. All milling and gluing shall be performed prior to treating.

### **8.3.3.3 Joints**

When the size of the glulam member exceeds the size of available lumber, joints must be used. End Joints are used to splice members lengthwise, and edge joints are used to splice widthwise. End joints shall be finger joints and shall be glued. Edge joints may be glued or unglued. If edge joints are not glued, then reduced shear design values must be used. The use of edge joints is discouraged by manufacturers as it is a labor intensive process. The exterior edge of all glulam members should be edge glued to prevent the ingress of water into the member.

For transportation and erection purposes, deck panels should not be more than about 60 ft [20 m] long. When splices in the length of deck panels are required, they should be made over a support.

### **8.3.3.4 Quality Control**

Glulam manufacturers must maintain a strict quality control program run according to ANSI/American Institute of Timber Construction (AITC) A190.1 specifications. This program includes inspection and

evaluation by a third party of manufacturing procedures, material testing, and quality control records. DelDOT’s *Standard Specifications* require that glulam manufacturers be licensed by AITC.

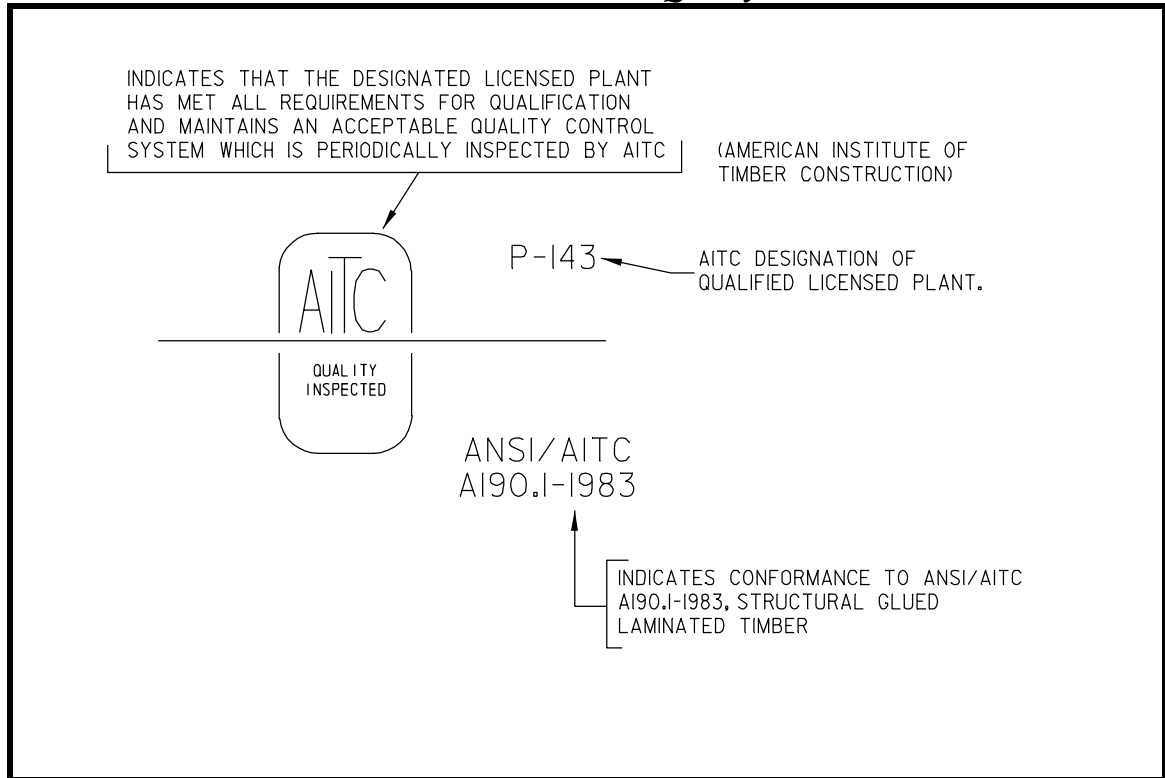
Members manufactured for DelDOT bridges must bear a custom product quality mark. A typical glulam quality mark is shown in Figure 8-2. In addition, the manufacturer must provide a certificate of material conformance at the time of delivery.

## **8.3.4 TABULATED DESIGN VALUES**

As previously discussed, wood strength varies with species, growth characteristics, loading, and condition of use. As a result, numerous design strength values are possible. In fact, so many combinations are possible, that it is not practical to publish them all. Therefore, timber design values are normally published by species, grade, and size classification for a set of standard conditions. Tabulated values are adjusted by modification factors to arrive at the allowable values used in each design.



**Figure 8-2**  
**Custom Glulam Product Quality Mark**



Tabulated allowable values and modification values are published in the National Design Standard (NDS) based on grading rules established by grading agencies. The values most applicable to bridge design are found in the *AASHTO Specifications*, Section 8.4.1.1.4. Separate tables are published for visually graded sawn lumber, mechanical stress rated (MSR) lumber, glue laminated members, and piles. The tables give allowable stress values for bending, tension, compression, and modulus of elasticity. The tables for visually graded lumber also contain values for shear and compression parallel to the grain.

In all cases, the engineer must exercise judgment to apply the condition of use adjustment factors to the specified

preservative treatment, structural use, and environmental conditions.

#### **8.3.4.1 Allowable Stress Values for Glulam Timber**

Tabulated allowable stress values of glulam are specified in the *AASHTO Specifications*, Section 8.4.1.2.3. This table includes bending about the X- and Y-axes and axially loaded conditions.

#### **8.3.4.2 Adjustments to Tabulated Values**

Tabulated values for sawn lumber and glulam are based on standard use conditions noted in the applicable tables. Frequently however, the actual values reported are not based on the same condition of use as the design application. Requirements for

adjusting tabulated values are given in the *AASHTO Specifications*, Section 8.4.4 and the National Design Standard (NDS). The type and magnitude of the adjustments, as well as the manner in which they are applied, vary with the type of material, strength property considered, and design application. Designers apply the modification factors by multiplying them by the tabulated value. Some modification factors are:

- **CM, moisture content factor**—compensates for the decrease in wood strength and stiffness as moisture content increases.
- **CD, deck factor**—compensates for the increased resistance to bending caused by stress laminating sawn lumber decks. Not to be used for stressed glulam panels.
- **CF, size factor**—tabulated values are based on standard size members. For larger members, strength decreases.

## 8.4 PRESERVATIVE TREATMENTS

Wood used in most bridge applications is attacked by agents that cause it to decay and lose strength. To protect the structure from decay and deterioration, wood used in bridge applications is treated with preservatives. All wood preservatives in their liquid form are hazardous waste; however, wood that has been treated is not considered hazardous waste.

Agents that cause wood to decay are called biotic agents, e.g., fungi and insects. Biotic agents require the following four conditions for survival:

- Moisture levels in the wood above the fiber saturation point.

- Free oxygen.
- Temperature between 50 and 90°F.
- Food (i.e., wood)

Wooden substructure elements buried or permanently submerged are safe from decay due to lack of free oxygen. All other elements of the bridge, however, are vulnerable to attack.

### 8.4.1 TYPES OF WOOD PRESERVATIVES

The most common method of controlling deterioration of wood is by making the food source toxic. This is done by introducing toxic preservative chemicals into wood cells using a pressure treatment process. Four basic types of wood preservatives are available: creosote, pentachlorophenol, waterborne preservatives and copper naphthenate.

#### 8.4.1.1 Creosote

Creosote, the oldest wood preservative, was first patented in 1831.

Creosote used for wood treatment is derived from the distillation of coal. The use of creosote in bridge applications should be done according to AASHTO standard specifications. In marine environments, 20 lbs/ft<sup>3</sup> [320 kg/m<sup>3</sup>] of creosote shall be retained. In non-marine environments, 12 lbs/ft<sup>3</sup> [190 kg/m<sup>3</sup>] of creosote shall be retained.

The excellent record of creosote as a wood preservative is well documented, with many applications providing more than 50 years of performance. Additional advantages of creosote are that it protects the wood from weathering and retards splitting associated with changes in moisture content. However, creosote does

not provide protection from a species of marine borer in warm saltwater.

The use of creosote has recently declined due to an increased desire for clean surfaces and complaints about handling creosoted wood. Most creosote used today is for applications involving minimal human contact. Current DelDOT practice is to not specify creosote treatment on highway bridges; creosote is specified on railroad bridges in accordance with AREMA Specifications.

#### **8.4.1.2 Pentachlorophenol (Penta)**

Penta is a synthetic pesticide derived from oil. Three types of Penta are manufactured: heavy oil, butane gas and light solvent. Heavy oil type penta, known as Penta Type A, is used in DelDOT bridges. Five percent Penta Type A is used by DelDOT to treat longitudinal decks, bridge rail and guardrail in accordance with the specifications.

Once treated, the surface is not paintable and should not be subjected to animal or human contact. Penta is preferred on timber decks because it seals out moisture that prevents warping and splitting. It is preferred on rails for the same reason and also because it leaves the wood with a rich brown appearance.

Penta is not effective against marine borers. Additionally, the EPA has placed penta on a list of restricted-use chemicals due to the trace presence of dioxins. Treated wood, however, is not considered hazardous waste by the Delaware Solid Waste Authority.

Hot-mix surfaces should not be placed on timber decks that have penta bleeding from the surface. In these cases, an approved blotter such as “Dry Sweep” is used to remove the free liquid preservatives.

#### **8.4.1.3 Waterborne Preservatives**

Waterborne preservatives include formulations of inorganic arsenical compounds in a water solution. These chemicals leave the wood surface relatively clean with a light green, gray-green, or brown color depending on the type of chemical used. Unlike the oil-based preservatives, waterborne formulations do not cause skin irritation and are suitable for use in areas of limited human or animal contact. After drying, the wood surface can also be painted or stained.

Waterborne preservatives shall conform to the DelDOT Specifications.

A disadvantage of waterborne preservatives is that they do not provide the protection from splitting and cracking due to moisture change that oil borne and creosote preservatives do. Waterborne preservatives do provide effective protection in marine environments where borer hazards are high.

#### **8.4.1.4 Copper Naphthenate**

Copper naphthenate is another type of oil-based wood preservative. Although not currently used for DelDOT applications, this wood preservative has proven itself in long-term stake tests. Its primary advantage is that it is considered environmentally safe and is not on the EPA’s list of restricted use pesticides. The primary disadvantage of this material is higher cost.

### **8.4.2 TREATED TIMBER SPECIFICATIONS**

Specifications for the preservative treatment of wood are maintained by The American Wood Preservers Association (AWPA), AASHTO, the American Institute

of Timber Construction (AITC), and the federal government. AWPAs standards are the most comprehensive and widely used source of specifications and treating process procedures for sawn lumber, glulam, and piling used for timber bridges. AASHTO's M133 specification closely parallels and references the AWPAs standard.

#### 8.4.2.1 Design Considerations

When selecting the most appropriate preservative treatment method, the designer should consider dimensional stability and surface appearance. In general, however, DelDOT prefers the use of waterborne preservatives on all exposed members except glue laminated members, bridge rail and guardrail where pentachlorophenol is preferred.

Dimensional stability is obtained by maintaining constant moisture content. Oil-based treatment methods provide dimensional stability by creating a water-resistant barrier on the wood surface. This reduces associated splitting and checking of the wood, which can provide an avenue for entry of fungi and insects.

Oil-based treatment methods provide a less desirable surface appearance than waterborne treatment methods. This is due to the bleeding of oil-treated members. The most severe bleeding typically occurs in members exposed to direct sunlight. In most cases, a small amount of bleeding is not harmful. Bleeding can be minimized by correctly specifying the treatment method. Ways to reduce bleeding are to:

- Specify the correct retention rate for the species, type of use, and preservative. AWPAs provides recommended retention rates.
- Specify empty cell process rather than full cell treating.

- Use clean creosote containing lower levels of xylene in solution.
- Use expansion baths at the conclusion of the treatment cycle.

## 8.5 HARDWARE

Hardware consists of any type fastener used to connect two or more timber members.

Proper design of hardware is important because it provides continuity to the member as well as strength and stability to the system. Connections shall be designed in accordance with the *AASHTO Specifications*, Chapter 8.4.2. Additional information may be obtained from the *National Design Specification for Wood Construction (NDS)*.

There are two basic types of connections: lateral and withdrawal. Lateral (shear) connections transmit force by bearing stresses developed between the fastener and the members of the connection. Withdrawal connections transmit load by pull-out resistance. Typical lateral and withdrawal type connections are shown in Figure 8-3. The different types of connection hardware available are shown in Figure 8-4 and described below:

- **Bolts**—Used in both lateral and withdrawal type connections where moderately high strength is required. Nuts and washers are applied to maintain tightness and transfer load. In lateral connections, load transfer takes place as bearing between the shaft of the bolt and the timber member. In withdrawal connections, load transfer takes place as bearing between the bolt head or washer and nut.

- **Timber connectors**—A steel ring or plate bolted between laterally loaded members. They provide high strength due to their large bearing area. Load transfer takes place as bearing between the plate and the member.
- **Lag screws**—Used similar to bolts but provide lower strength. This type of connection can be used in both lateral and withdrawal type connections. Thread interaction with the wood provides strength in withdrawal type applications. In lateral connections, the strength mechanism is bearing between the shaft of the screw and the timber member. Lag screws are typically used where access to the connection is convenient from only one side.
- **Nails and spikes**—Driven fasteners are used primarily for non-structural applications. This type of fastener is susceptible to loosening due to vibration and moisture change.
- **Drift bolts and drift pins**—long unthreaded bolts or pins driven into pre-drilled holes. These are typically used for lateral connection of large timber members and are not suitable for withdrawal connections due to low resistance to withdrawal.

Selection of a fastener type depends on the type of connection and required strength. Connections must be designed to transmit the load throughout the life of the structure without causing splitting, cracking or deformation of the wood.

Washers should be used under fastener heads that are in contact with wood. Washers may be omitted under heads of special bolts when the size of the head is sufficient to develop connection strength without excessive wood crushing. Corrosion

protection of washers should be hot dip galvanizing in accordance with AASHTO specification M111 or M232. Common washer types for timber connections are shown in Figure 8-6.

## 8.6 SUPERSTRUCTURE DESIGN CRITERIA

The design of timber bridges closely parallels that of other types of bridges. The design method used for timber bridges is the LRFD Method as specified in the *AASHTO Specifications* Section 8. In the LRFD method, the factored loads on the bridge must be less than the factored resistance for the material. Beams are designed for bending, buckling, deflection, shear, and bearing. Tension members are designed for axial stress. Compression members are designed for axial stress, buckling, and bearing stress. Design of timber structures is typically governed by deflection, shear and connections.

Important in the design of timber structures are loads, impact, buoyancy, and deflection. These factors as they relate to timber bridges will be discussed in the following sections. For additional superstructure design criteria, refer to Sections 2.5 and 2.6 of this manual.

### 8.6.1 LOADS

Loads shall be in accordance with Chapter 3 of the *AASHTO Specifications*. Load combinations and load factors shall be applied for the various limit states given. Structural elements are sized based on limit state loads, which produce the maximum stress.

### **8.6.1.1 Load Distribution**

Load distribution of timber longitudinal deck type bridges shall be in accordance with the *AASHTO Specifications* Section 4.6.2.3, Equivalent Strip Widths for Slab Type Bridges. Load distribution of existing timber beam type bridges shall be in accordance with the *AASHTO Specifications* Section 4.6.2.2, Beam-Slab Bridges.

### **8.6.1.2 Impact**

Impact increases the equivalent static load due to bouncing and vibration caused by moving loads. The impact factor used in determining factored loads for timber bridges is reduced by 50% from that used for steel and concrete bridges. This is due to the excellent shock absorbing capability of timber materials. Impact factors shall be applied in accordance with the *AASHTO Specifications* Section 3.6.2.3, Dynamic Load Analysis of Wood Components.

### **8.6.1.3 Buoyancy**

Buoyancy is the resultant upward force acting on a submerged body. Buoyancy must be considered for any portion of a bridge that is or may be submerged. Buoyancy reduces the forces resisting overturning loads. Substructure overturning loads are typically stream current and wind loads. Foundation elements and connections must be sized to resist overturning when buoyant effects are considered.

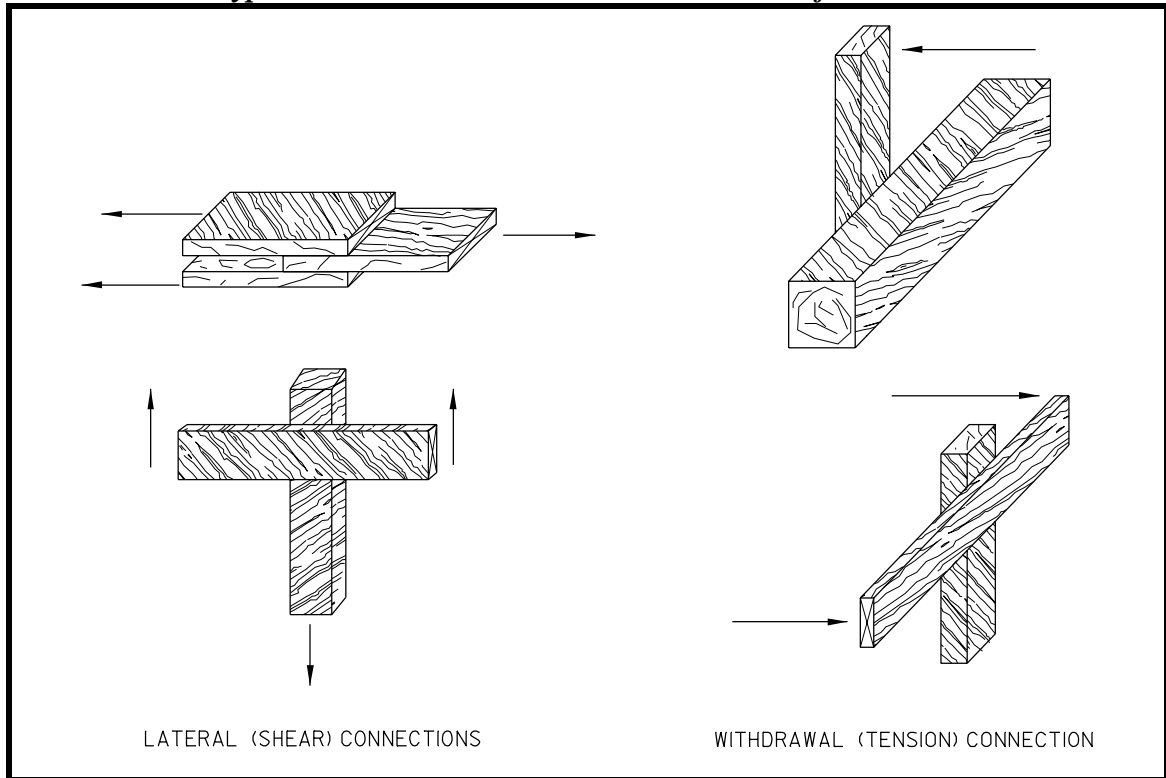
## **8.6.2 DEFLECTION**

Deflection of timber structures is based on service loads and is limited to  $1/425$  of the span length. Deflection should be based and calculated using the equivalent width, as calculated for moment.

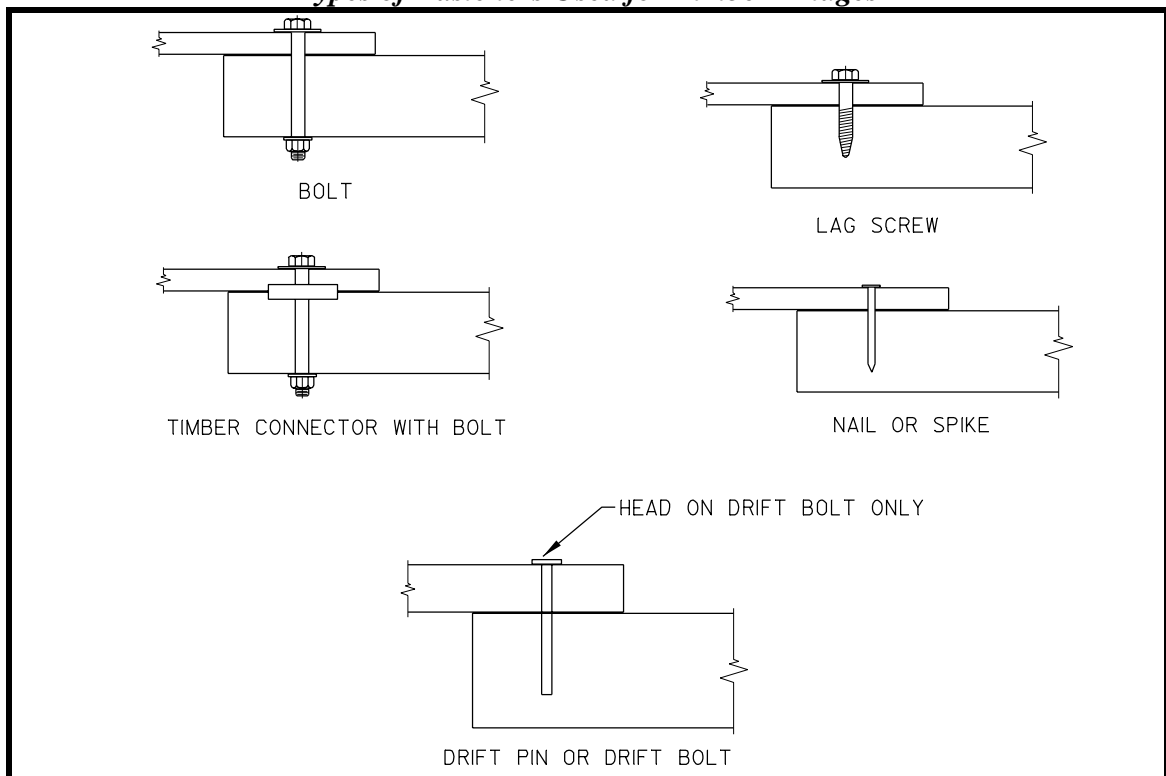
## **8.7 LONGITUDINAL DECK DESIGN**

Longitudinal timber deck bridges are typically constructed of glue laminated deck panels that are stressed together using threaded steel rods. Longitudinal decks act as a slab; therefore, they are subject to bending and shear in both the longitudinal and transverse directions. Longitudinal bending controls the deck thickness, while transverse bending, shear and deflection controls the compressive prestress that must be applied. Examples of the effects of transverse bending and shear are shown in Figure 8-7. Decks should be designed to minimize these effects. Design guidance for stress laminated timber decks is found in Section 9.9.5 of the *AASHTO Specifications*.

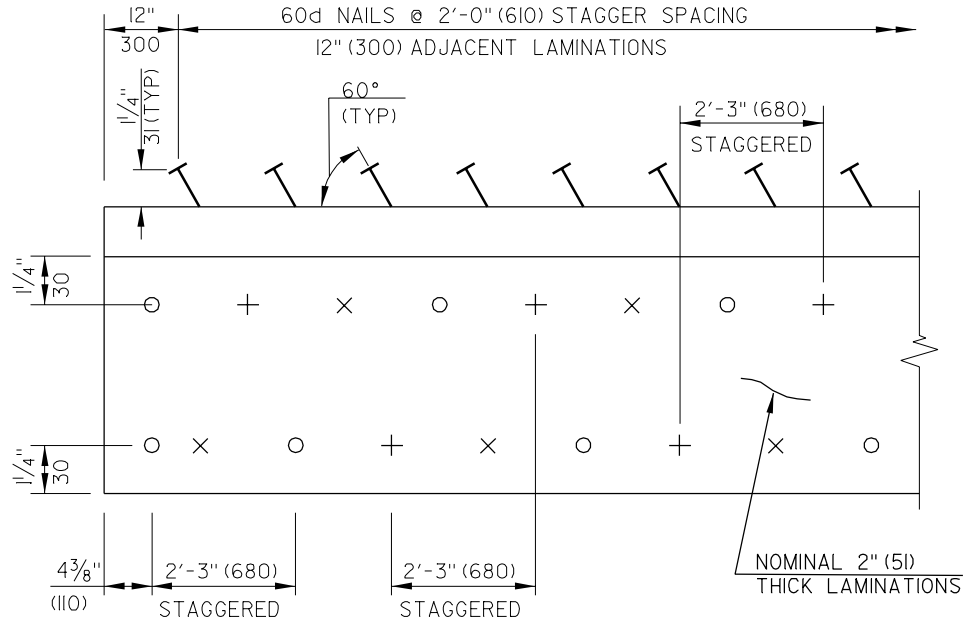
**Figure 8-3**  
**Typical Lateral and Withdrawal Connections for Timber**



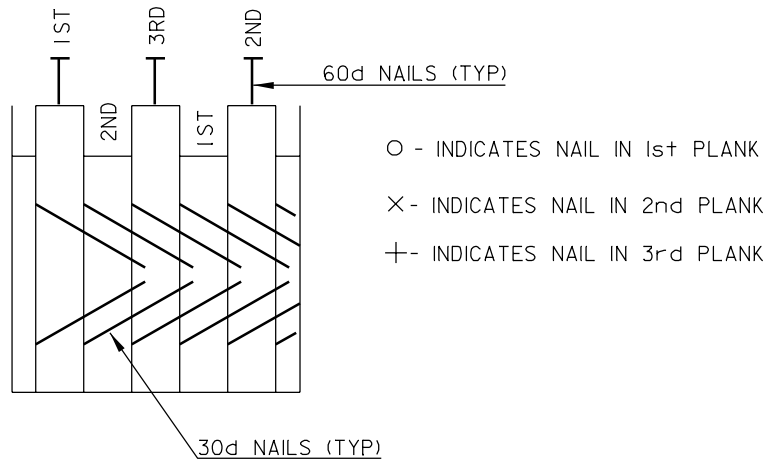
**Figure 8-4**  
**Types of Fasteners Used for Timber Bridges**



**Figure 8-5a**  
**Nailing and Uplift Spike Details**



NOTE: ALL DIMENSIONS ARE IN INCHES (MILLIMETERS).

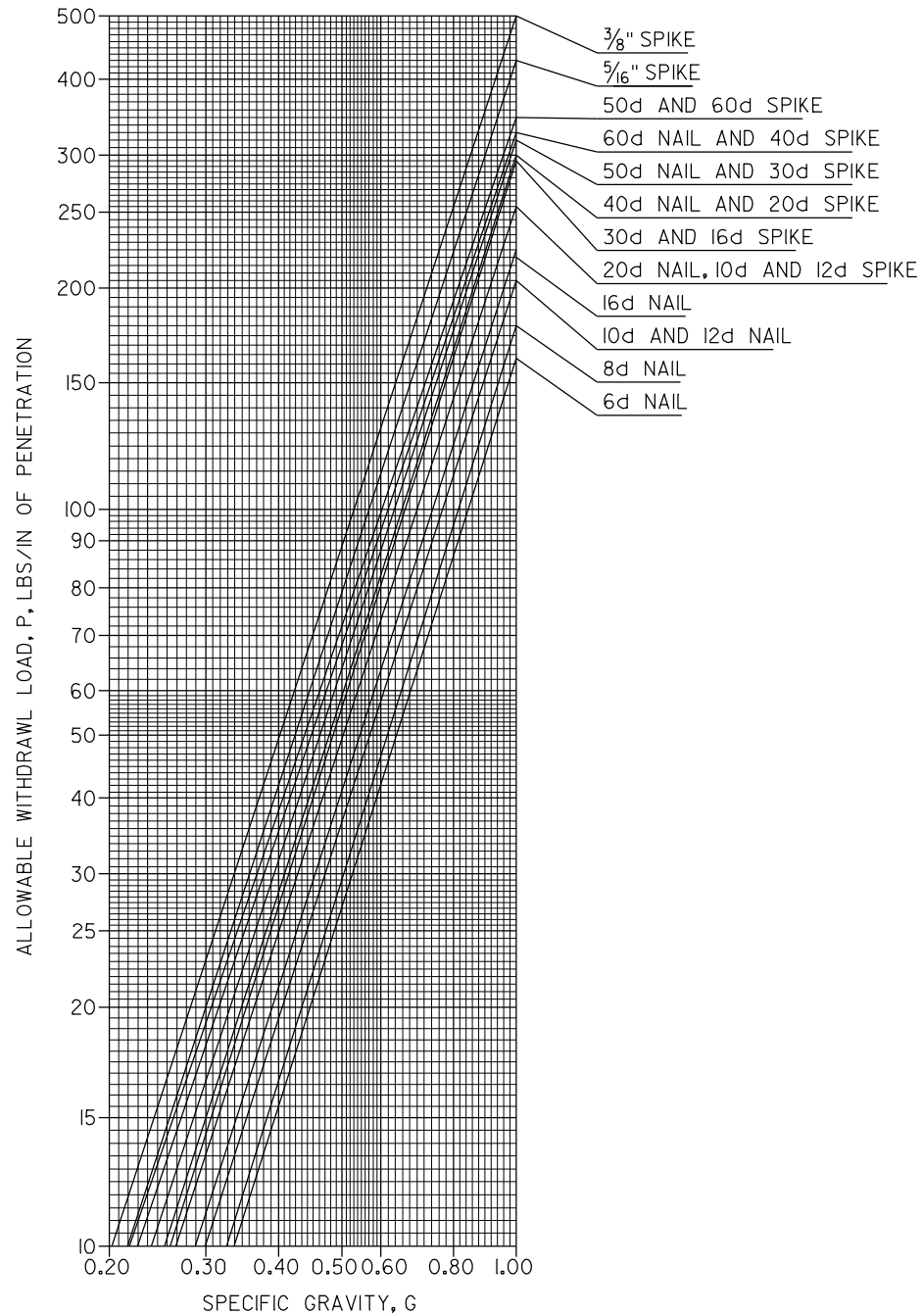


NAILING & UPLIFT SPIKE DETAIL

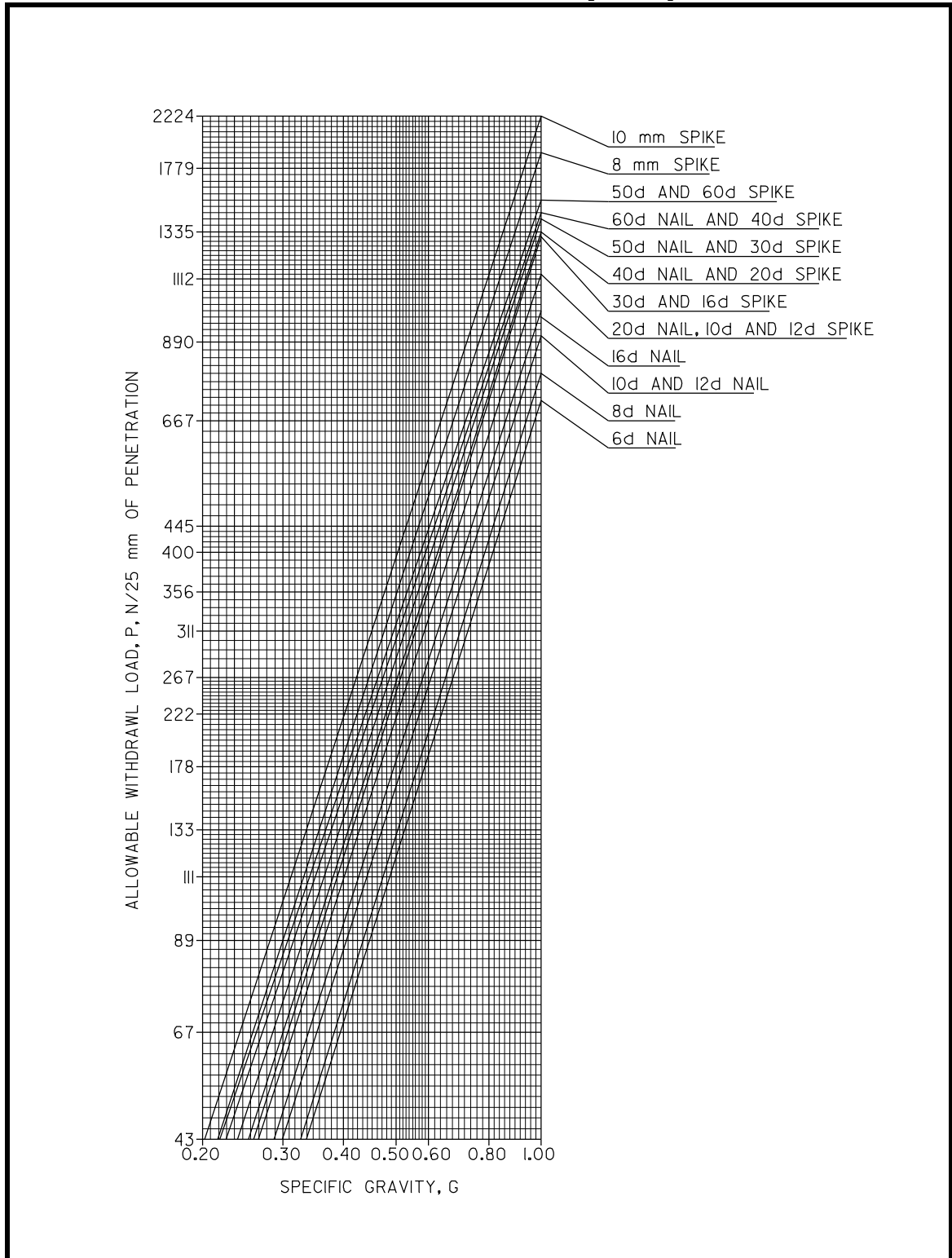
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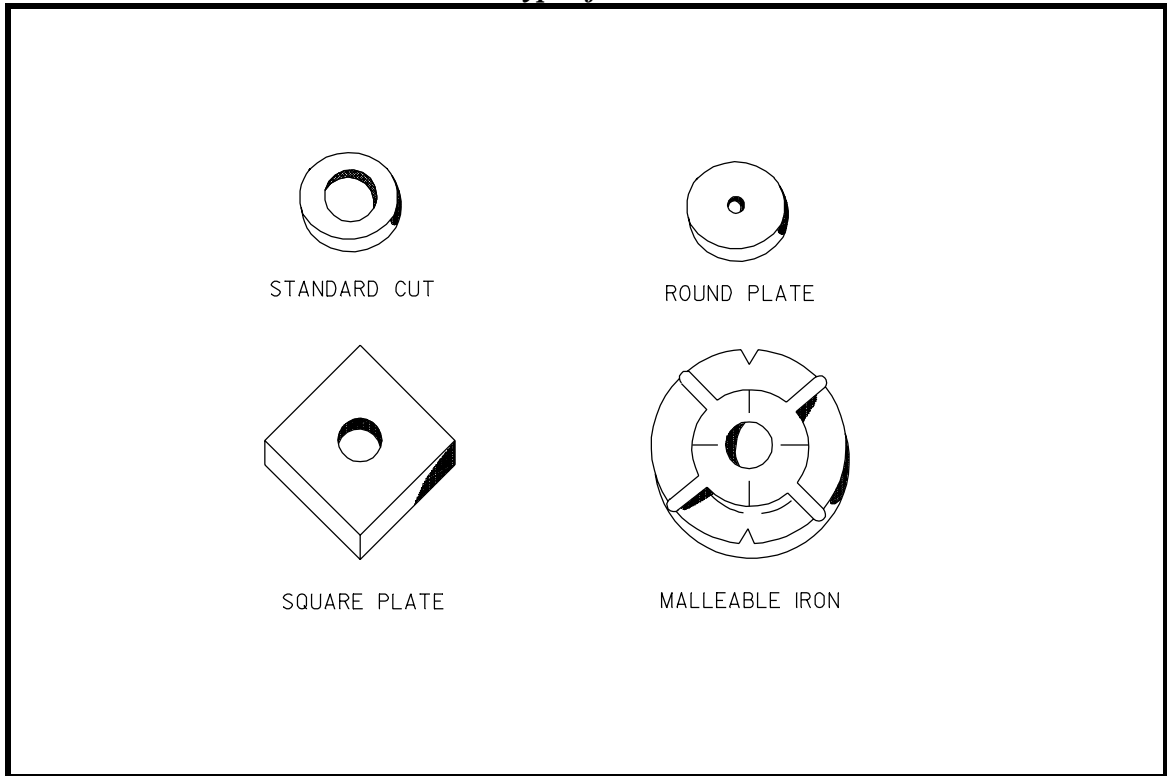
**Figure 8-5b**  
**Allowable Withdrawal Load (U.S. Customary)**



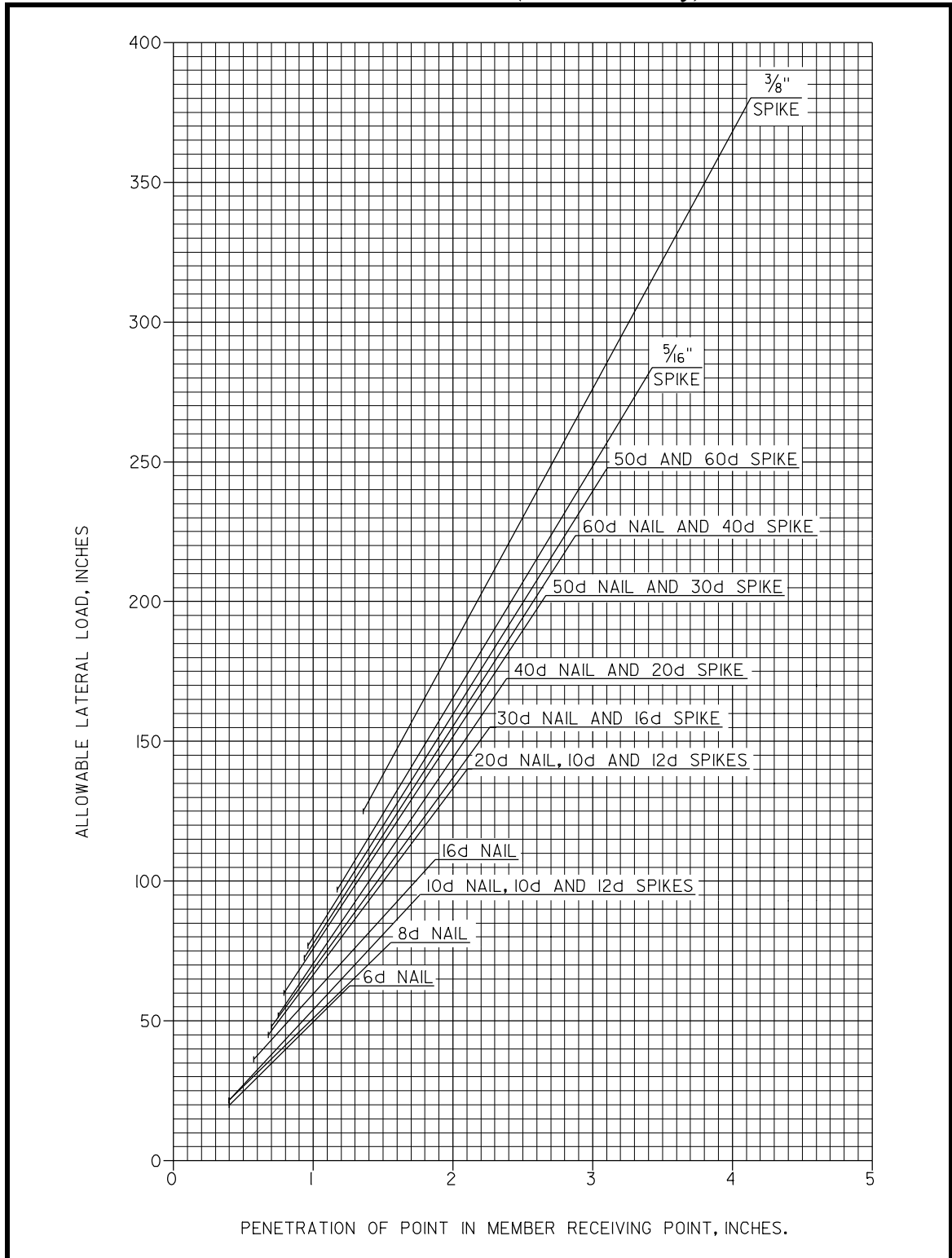
**Figure 8-5c**  
**Allowable Withdrawal Load [Metric]**



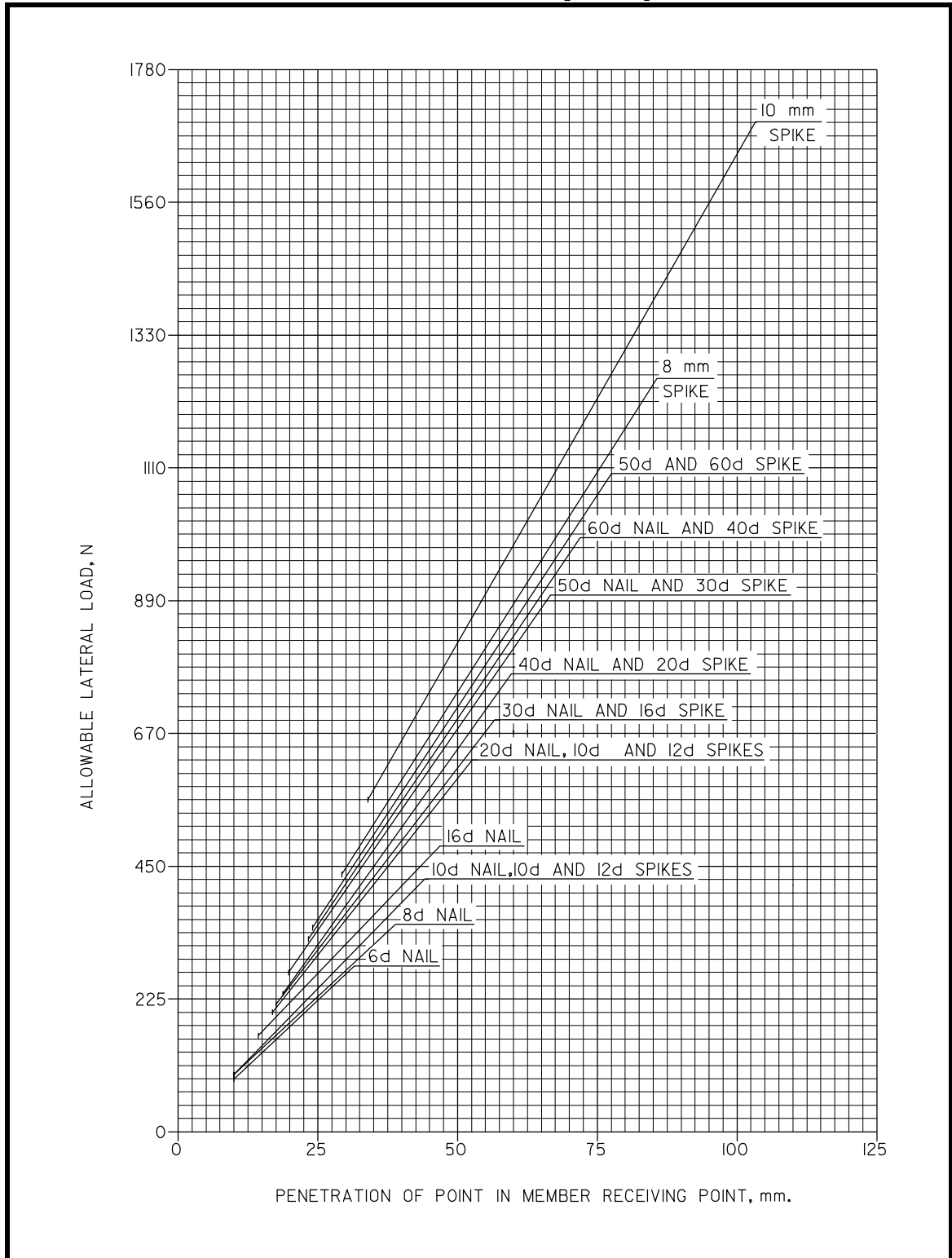
**Figure 8-6a**  
***Common Washer Types for Timber Connections***



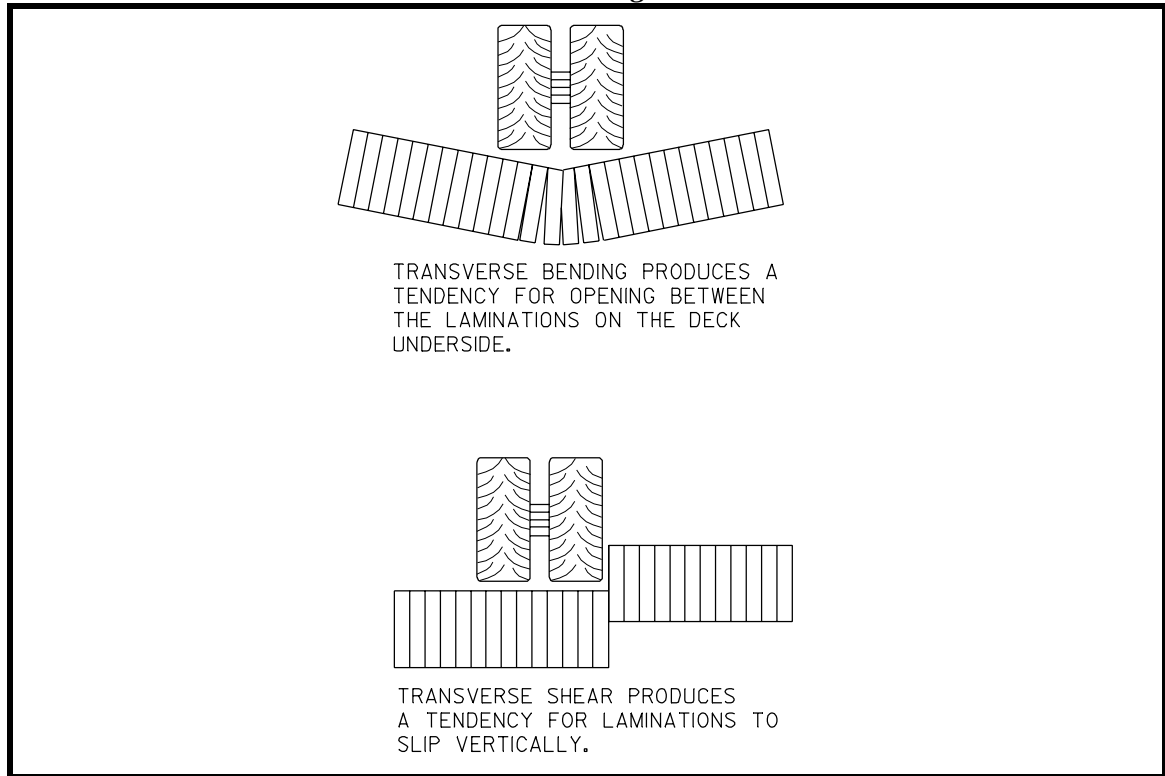
**Figure 8-6b**  
**Allowable Lateral Load (U.S. Customary)**



**Figure 8-6c**  
**Allowable Lateral Load [Metric]**



**Figure 8-7**  
**Transverse Bending and Shear**



Glue laminated deck panels for longitudinal timber deck bridges are prefabricated and treated off site in 3 to 5 ft [0.9 to 1.5 m] wide sections. The panels are constructed by gluing together timber planks which are 1 ½" [38 mm] thick for western species and 1 3/8" [35 mm] thick for southern pine. These timber planks are stress-rated and glued together with a wet-use structural adhesive to form panels. Preservative treatment of the lumber is with pentachlorophenol, an oil-based preservative which limits moisture content changes and associated dimensional changes in lumber that can result with change in moisture content. The species of lumber used in wood lamination should be as specified in Section 8.2.1.

Unlike most sawn lumber, the size specified for longitudinal decks is the actual dimensions of the member, rather than the nominal size. Standard widths are based on dressed sizes of sawn lumber. Once glued, panels are then surfaced. Glulam panels, however, are not surfaced on the top side to provide better bond between the lumber and wearing course.

To provide stiffness to the deck and limit differential movement, glulam panels are transversely post tensioned. The prestressing system consists of prestressing elements and anchorage. The prestressing elements are normally threaded rods that conform to ASTM A722, Un-coated High-Strength Steel Bars for Prestressing Concrete. The rods have a minimum

ultimate stress in axial tension of 150 ksi [1034 MPa] and are available in diameters of 5/8 in [15.9 mm] to 1-3/8 in [35.0 mm]. Anchorage consists of a nut bearing on either a channel or plate. The rods are placed at regular intervals and can be run either internal or external to the timber planks. All new construction shall have internal rods. Once all components are in place, the rods are tightened on the panels using a hydraulic jack, thereby creating sufficient friction between the panels to cause them to perform structurally as a unit. See Figure 8-8a.

The post tensioning system must be protected from corrosion. The rods and associated hardware are typically hot-dipped galvanized in accordance with ASTM A123, A143 and A153. Precautions shall be taken to prevent hydrogen embrittlement of the high-stress rods. Polyethylene sleeves with hydrophobic grease may be used with galvanization.

The stressing sequence of the rods is very critical due to time-related stress loss. However, if losses can be limited to a maximum of 60%, the deck will still perform adequately. Stressing is generally carried out from one end of the bridge to the other in a series of passes. As each rod is stressed, it reduces tension on adjacent rods. Therefore, the rods must be re-stressed. Typically a uniform stress level can be achieved after a total of 4 passes during initial stressing. After initial stressing, re-stressing should be performed at 1 week and 5 weeks. Multiple passes may again be required to achieve uniform stress. Additional stressing can be carried out later as part of routine maintenance if required. The overall system is very stiff and provides a firm base for an asphalt surface. With this type of construction, spans of up to 30 ft [9 m] are possible.

The following are some of the advantages of this system:

- Decks can be prefabricated locally.
- Decks act as one unit (i.e. no differential movement of panels or laminations), which does not adversely affect the wearing surface.
- Re-stressing the deck as necessary can control delamination.
- Members can be spliced suitable for fabricating almost any length.
- This method can be used to rehabilitate delaminating glue and nail laminated decks.

To decrease construction time, decks can be prefabricated off-site and brought to the job site already stressed. This eliminates the need for repeated trips to the site to stress the bridge.

Allowable stresses for glue laminated panels are given in the *AASHTO Specifications*, Section 8. Guidance for design of longitudinal glue and stress laminated decks is provided in the *AASHTO Specifications*, Section 9, and the United States Department of Agriculture (USDA) *Timber Bridge Manual*, Chapters 8 and 9, respectively. The designer should check available sizes of glue laminated members prior to specifying them.

## **8.8 RAILING FOR TIMBER DECKS**

Railings are provided on timber bridges to safely restrain an impacting vehicle, bicycle, or pedestrian. AASHTO specifications require all bridge rails to meet two requirements. First, the railing must be tested and approved in accordance with

NCHRP Report 350, Tested Roadside Hardware. Second, the rail must be mounted to the deck with sufficient strength to withstand a static load as described in Section A13.2 of the *AASHTO Specifications*. A typical DelDOT timber bridge rail consisting of horizontal members mounted on timber posts is shown in Figure 8-8. This railing provides performance level 1 protection. Glulam parapets can also be used as railings. More economical systems may be available.

Standard plans for crash-tested bridge railings for longitudinal wood decks are contained in the *USDA General Technical Report FPL-GTR-87*.

## **8.9 HOT-MIX WEARING SURFACES FOR TIMBER DECKS**

Wearing surfaces are placed on some bridge decks to form the roadway surface. The wearing surface is important because it is the only part of the bridge that comes in direct contact with vehicles. Therefore, the wearing surface provides ride quality and skid resistance for vehicles and protects the timber deck from abrasion and wear.

Hot-mix pavement is the preferred wearing surface on timber bridges in Delaware. Hot-mix pavement protects the wood from abrasion and moisture and provides a smooth, skid-resistant surface. Hot-mix pavements normally perform well; however, the following factors can influence compatibility:

- Deck deflection, which must be limited to prevent cracking.
- Method of preservative treatment and amount of excess preservative.

The top of deck elements should be left rough to insure bonding with bituminous materials. The hot-mix used should be 1 in [25 mm] minimum Type C Hot-mix. Waterproof membranes are not used under the hot-mix. When practical, the deck should not be paved for 30 to 45 days after the deck material has been treated with preservative. Before the wearing surface is placed, the surface shall be cleaned of any excess preservative oil with the application of a surface blotter (“Dry Sweep”) in order to improve hot-mix bonding. Prior to placing the hot-mix, a tack coat should be applied to bond the hot-mix to the deck. The overlay should be crowned at a 2% minimum cross slope to insure adequate drainage of the deck.

## **8.10 SUBSTRUCTURE DESIGN**

The substructure is the portion of the bridge that supports the superstructure and transfers load to the supporting soil or rock. Substructures normally consist of abutments and pile bents.

Design of piles and retaining walls is described in Chapter Six. Material properties of the timber components are given in the *AASHTO Specifications*, Section 8.4, Material. Preservative treatment of all substructure elements should be carried out as per Section 8.4 of this manual.

### **8.10.1 TIMBER ABUTMENTS**

Abutments support the ends of the bridge. Timber abutments are typically supported on timber piles with glulam or sawn lumber pile caps. Abutments are constructed with vertical faces. Vertical faces require the abutment to act as a retaining wall. The abutment designed should consider scour



and scour protection. Vertical face abutments constructed of timber sheeting consist of two layers of boards placed behind piles or posts. The first layer, horizontal backing, is attached horizontally to the piles or posts. The horizontal backing is placed to a depth of one foot [0.3 m] below the mud line. Vertical tongue and groove sheeting is then driven behind and attached to the horizontal backing. A geotextile fabric is attached to the back layer of boards to ensure that backfill material does not escape through the joints and cause settlement of the backfill. See Figure 8-9.

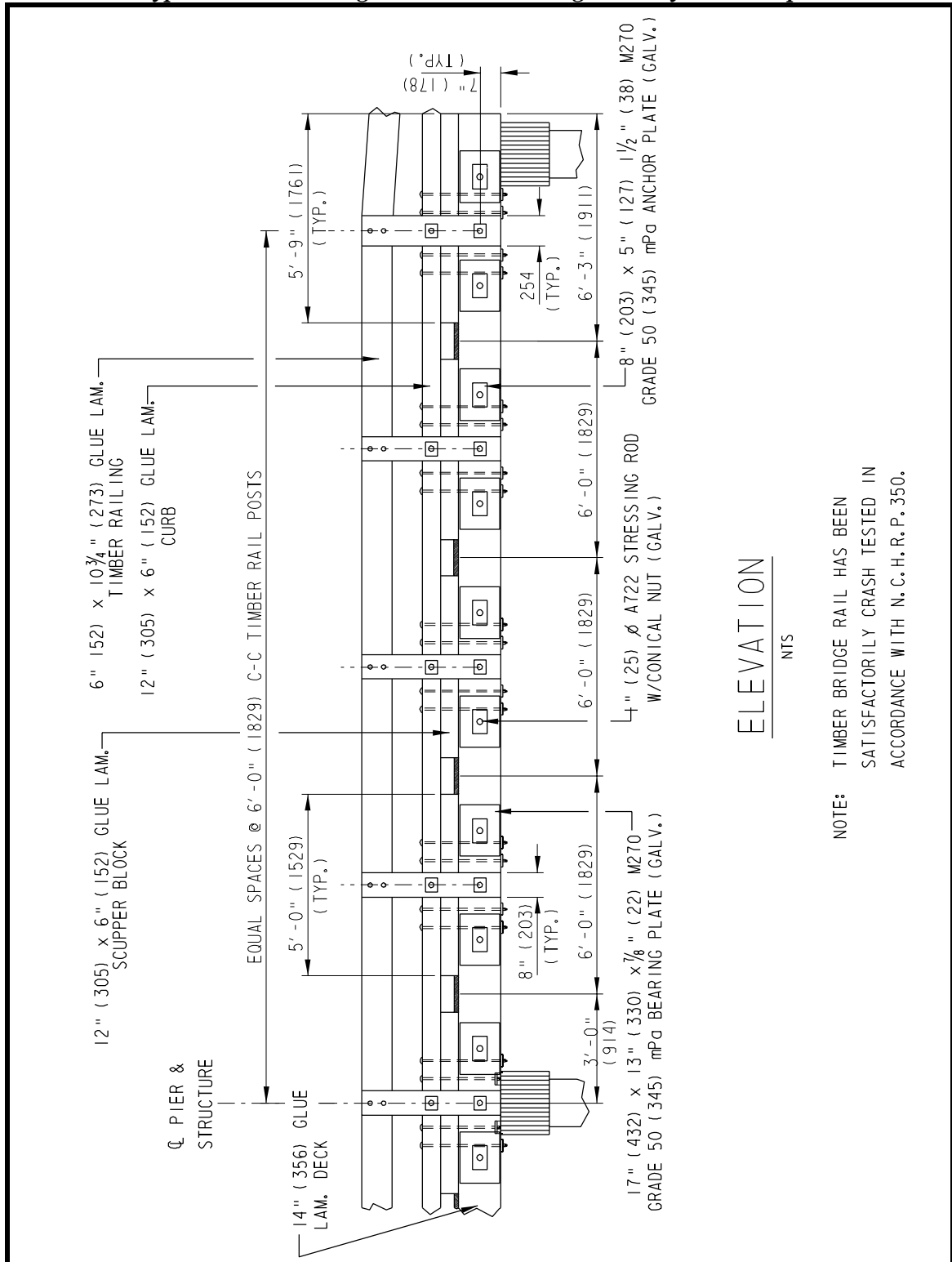
### **8.10.2 TIMBER BENTS**

Timber bents are typically constructed with timber piles. Pile bearing values shall be as described in Section 6.2.2.4. Care must be applied to ensure that the top of the pile is protected from moisture. Moisture protection for the tops of piles is usually provided by covering the top of the pile with a zinc or copper cover plate, folded down over the sides of the pile a distance of at least 3 in [75 mm] and firmly nailed in place with galvanized or copper nails. See Figure 8-10.

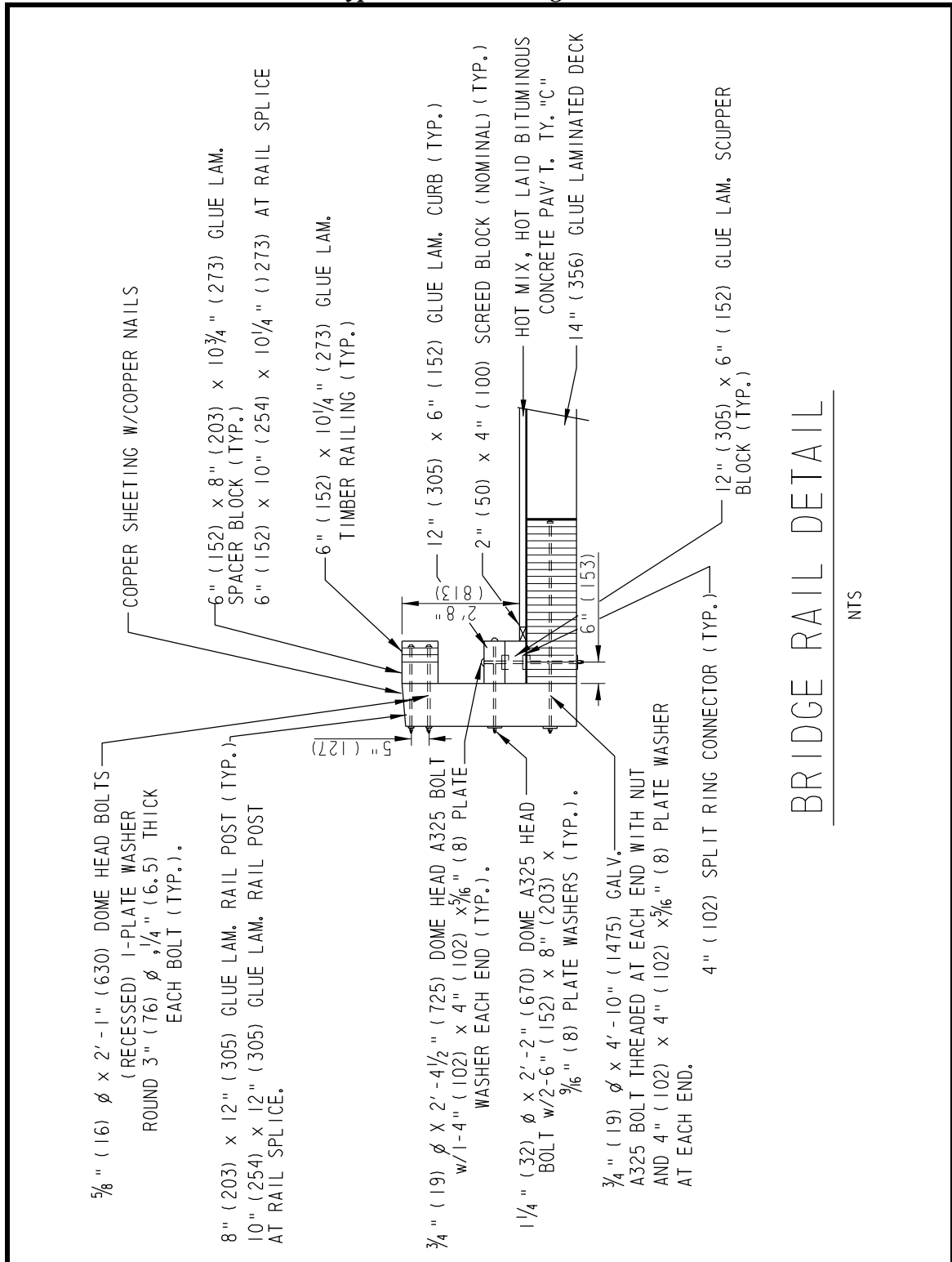
### **8.10.3 TIMBER FENDERS**

Timber fenders are normally placed around piers and abutments whenever they are in or near a navigable channel. Timber fenders protect substructures from impacts with a moving vessel. Fenders should be designed to absorb the impact of the largest vessel anticipated to use the channel. Fenders also delineate and guide boat traffic through the bridge opening.

**Figure 8-8a**  
**Typical Timber Bridge Rail and Stressing Rod Layout Example**



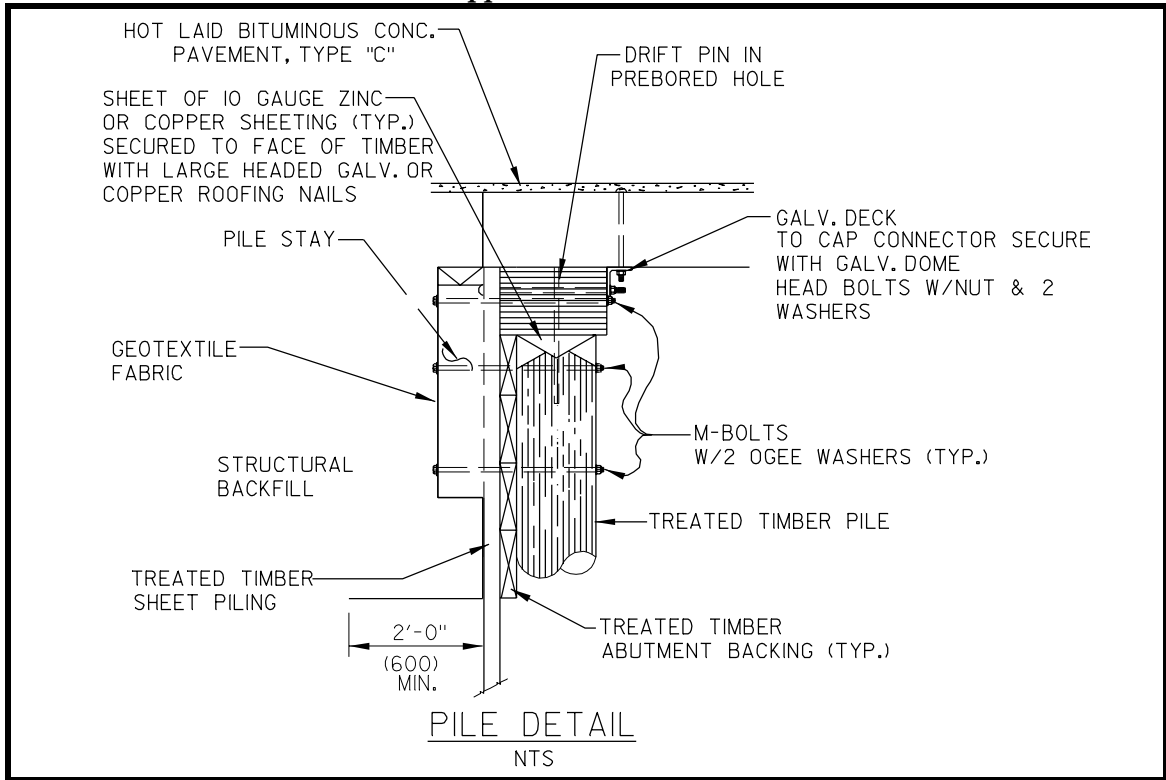
**Figure 8-8b**  
**Typical Timber Bridge Rail**



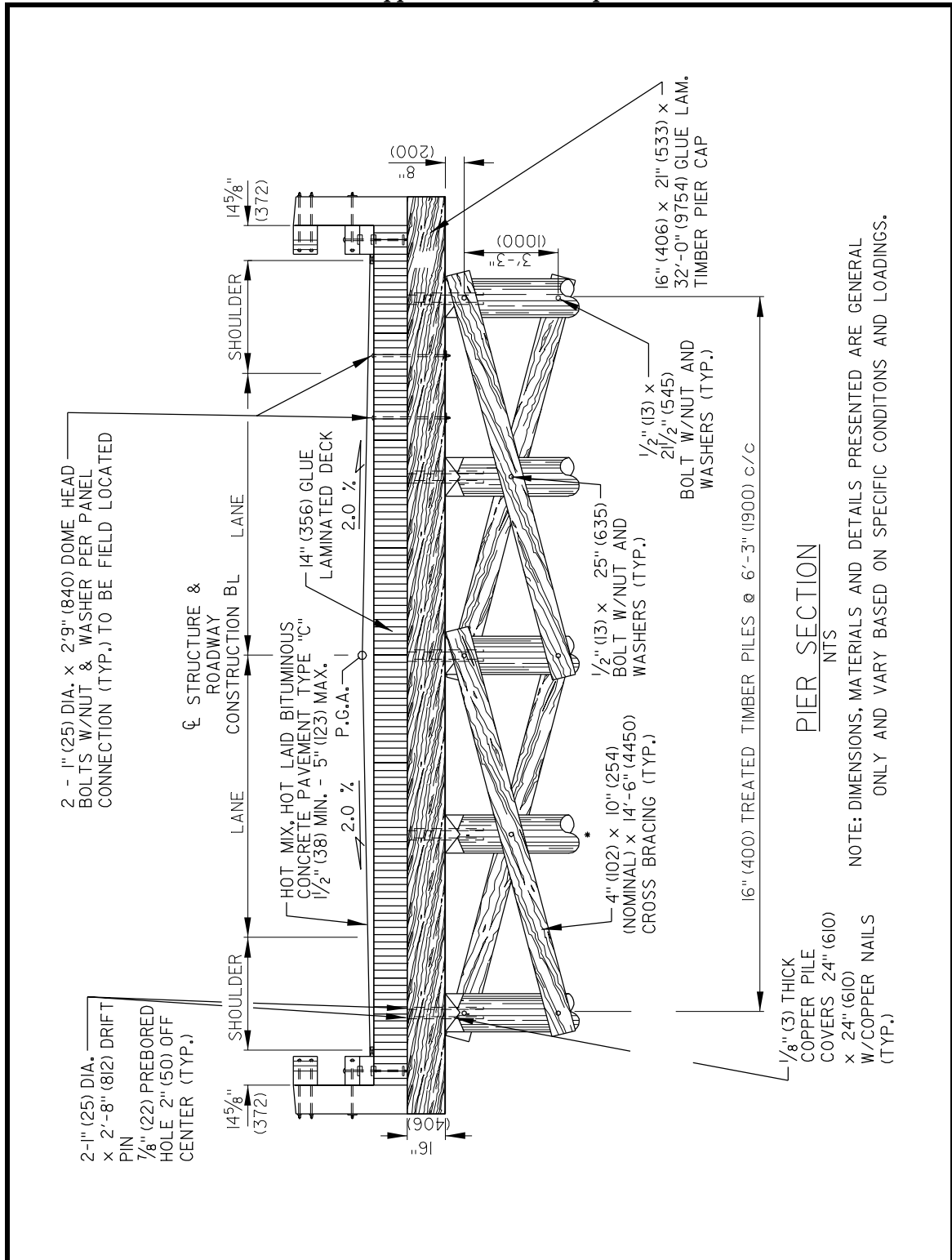
BRIDGE RAIL DETAIL

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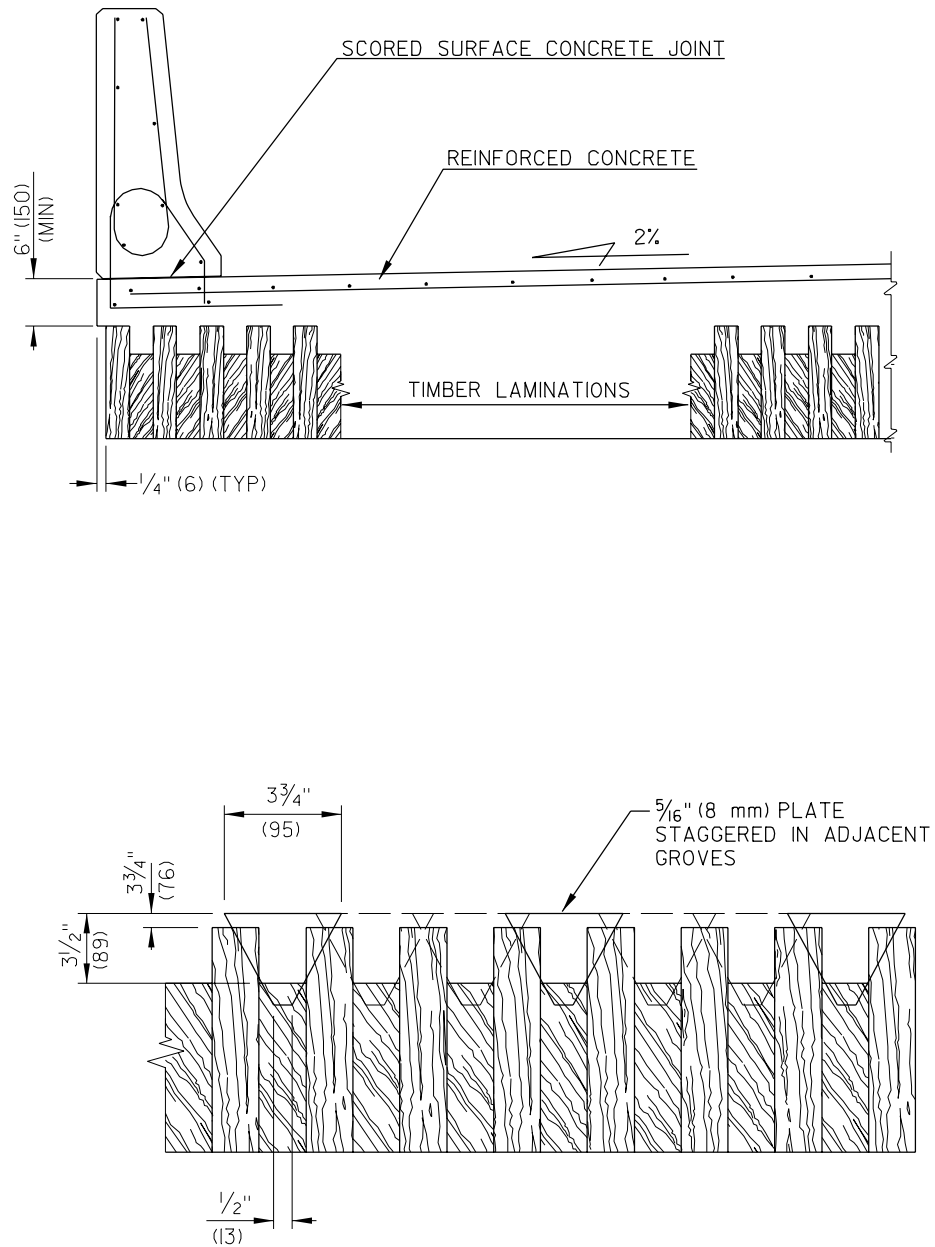
**Figure 8-9**  
**Pile Supported Abutment Detail**



**Figure 8-10a**  
**Pile Supported Bent Example**



**Figure 8-10b**  
**Typical Shear Developer Detail**



TYPICAL SHEAR DEVELOPER DETAIL  
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